EFFECT OF SPECIMEN LENGTH ON LONGITUDINAL GAS PERMEABILITY IN HARDWOODS[1]

Peter J. Fogg and *Elvin T. Choong*

School of Forestry, Wildlife, and Fisheries
Louisiana Agricultural Experiment Station
Louisiana State University Agricultural Center
Baton Rouge, LA 70803

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ABSTRACT

A study was carried out to determine whether the longitudinal gas permeability of hardwoods is affected by specimen length. The results indicate that in most woods tested, the permeability remains constant as length is reduced, except for lengths below 0.75 inch. Thereafter, with decreasing specimen length, permeability increases drastically. The large differences in permeability of samples of different length are attributed to random blockages in the capillary structure of the wood.

Keywords: Darcy's Law, fluid flow, wood anatomy.

INTRODUCTION

Darcy's Law has been used to describe the flow of fluid through a porous medium such as wood (Siau 1984). This law may be expressed as:

$$Q = k(\Delta P/L)$$

where ($\Delta P/L$) represents the pressure difference per unit length, Q is the rate of fluid flow, and k, the coefficient of permeability, is a constant. Bramhall (1971), however, indicated that the steady-state longitudinal gas penetration of Douglas-fir low-permeability sapwood and heartwood deviated from Darcy's Law. The permeability constant increased with a decrease in sample length, which he attributed to the random blockage by aspirated pits so that the number of conducting tracheids was reduced exponentially with depth of penetration. The literature does not indicate whether this non-Darcy behavior due to length is characteristic of all woods. The hardwoods, in particular, do not have aspirated pits; also, the vessels in the hardwoods should be more conducive to fluid flow through wood. Therefore, this study was undertaken to determine whether the gas permeability in hardwoods is affected by sample length.

MATERIALS AND METHODS

Four hardwood species, American sycamore (*Platanus occidentalis* L.), American elm (*Ulmus americana* L.), hickory (*Carya* spp.), and mesquite (*Prosopis juliflora* (Schwarts) De Cand.), were chosen for this study. For each species, five side-matched, longitudinal specimens measuring ⅝-inch in diameter were taken with a Greenlee plug cutter from both the sapwood and heartwood zones of sycamore and elm wood blocks in the air-dried condition. In hickory and mesquite, only the heartwood specimens were prepared because sapwood was not

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available. All specimens were placed in a desiccator over phosphorus pentoxide to slowly reduce their moisture content to approximately zero percent. Permeability measurements in the axial direction were made in an apparatus described by Choong et al. (1974) using nitrogen gas as the fluid medium, at an average pressure of 1.2 atmospheres. The upstream and downstream pressures were adjusted to keep the same mean pressure for all permeability determinations. The specimens, initially 2.0 inches in length, were cut successively to 1.75, 1.50, 1.25, 1.00, 0.75, 0.50, 0.25, and 0.15 inches. Permeability measurements were made at each sample length.

The specific permeability K, which is the product of permeability k and viscosity μ, was calculated using Darcy's Law for gas, as follows:

$$K = \frac{\bar{Q}_a \mu L P_a}{A\bar{P}(\Delta P)} \quad \text{(Darcy, or cm}^2\text{-cp/sec-atm)}$$

where $\bar{Q}$ (cc/sec) is the flow rate at mean pressure $\bar{P}$ (atm) $= (P_1 + P_2)/2$, $\bar{Q}_a$ (cc/sec) is the flow rate at atmospheric pressure $P_a = 1$ atm and ambient temperature of 72 F, ΔP (atm) is the pressure drop $(P_1 - P_2)$, μ is the viscosity of nitrogen (0.0178 cp), A (cm^2) is the surface area of the sample through which the flow took place, and L (cm) is the length of the sample.

RESULTS AND DISCUSSION

With the exception of American elm sapwood, the permeability remained constant as specimen length decreased to 0.75 inch (Fig. 1). A further reduction in sample length increased the permeability. Fogg (1968) and Banks (1970) found the same trend with softwoods. In Fogg's data, the longitudinal air permeability of loblolly pine sapwood remained relatively constant above 1.0 cm, but increased considerably with decreasing lengths below 1.0 cm. This increase at shorter lengths was thought to be due, in part, to the increased proportion of tracheids open at one or both ends of the sample, particularly at lengths below 0.5 cm. Banks (1970), working with Scots pine and Norway spruce, also reported drastically increased longitudinal air permeability in both species at lengths below 2.0 cm.

The decrease in permeability at increasing lengths indicates either partial or total blockage of some of the conducting pathways as specimen lengths exceed a few cell lengths in both softwoods and hardwoods. The initial penetration of refractory woods is a reflection of the phenomenon of high permeability over short lengths. In the case of hardwood sapwood, the vessels probably contribute most to axial flow (Greaves 1974). Tamblyn (1960) indicated that longitudinal penetration into vessels by liquids is largely affected by the occurrence of tyloses. The effect of shortening sapwood samples cannot be explained by the opening of more of these vessel flow paths, since the vessels of sapwood do not have tyloses. Yet, both elm and sycamore sapwoods exhibited the same phenomenon as the heartwoods studied. If this is the case, what causes the blockage in hardwoods? The blockage in softwoods can be explained, at least in part, by pit aspirations. No such mechanism is available in hardwoods.

The sharp increase in permeability in this research occurred at lengths shorter than 0.75 to 0.50 inch, whereas fiber lengths are likely to be more in the range of 0.10 to 0.20 inch. Thus the change in permeability is not attributable to the change

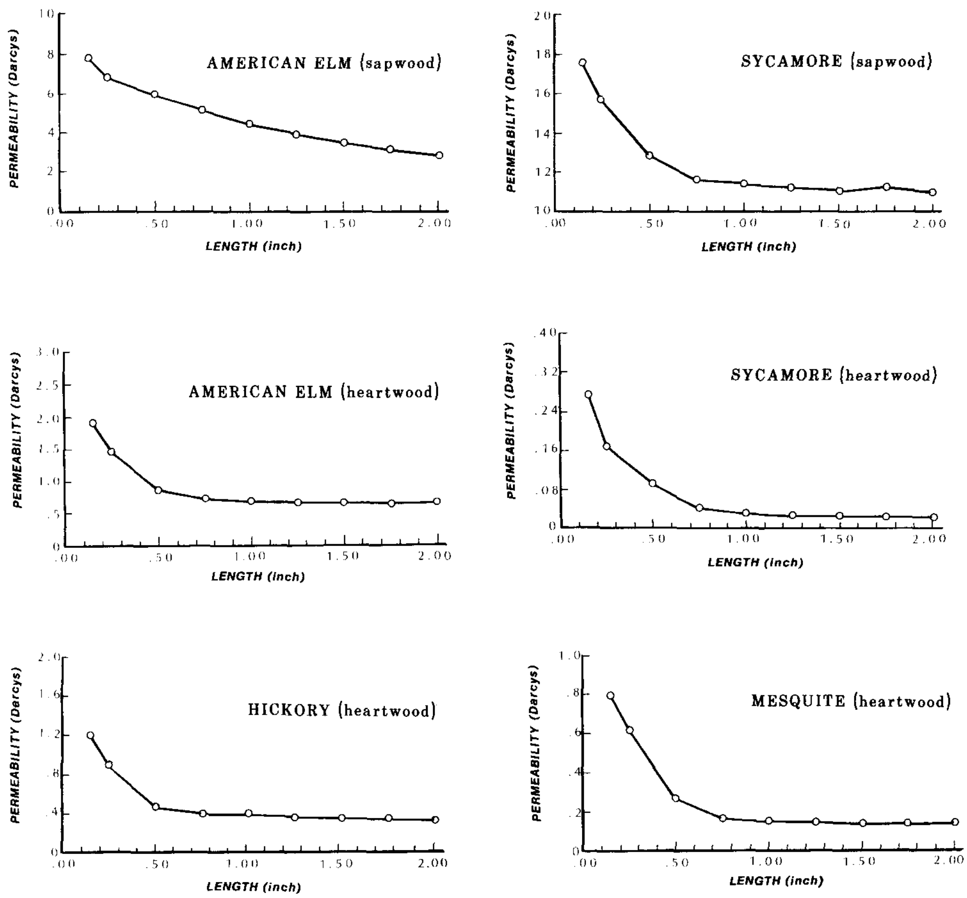

FIG. 1. Permeability of four hardwoods as related to specimen length.

in the number of clear fiber pathways. The shortening of samples of hardwood heartwood may be hypothesized as resulting in the partial opening of more vessel paths, since tyloses or deposits in the pores are not always uniformly distributed along vessel lengths.

For all species or wood-types (sapwood or heartwood) except sycamore heartwood, the change in permeability was of the order of approximately two to four times. Sycamore heartwood, however, changed by a factor of about 14. This indicates that the change was not due to the physical dimensions of the samples per se, but to a change in the effective pathways within the sample.

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